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BACK-SCATTER OBSERVATIONS AND PROBLEMS OF LONG-DISTANCE RADIO COMMUNICATION AND BROADCASTING

- USSR -

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(Methods of adapting BSO /back-scatter observations7 during work on one frequency, which permit under operating conditions receiving the necessary information on the state of radio wave propagation conditions, determining the necessary parameters, and judging the degree of reliability of radio reception, are cited.)

It is known that an engineer, in carrying out radio communication and broadcasting via short wave over great distances, must continuously know the state of radio wave propagation conditions on the routes, i.e., whether this state is normal or disturbed, and if it is disturbed, to what degree. In any state of the ionosphere it is necessary for him to know the optimum frequency, the boundary of the zone of silence on this frequency, the tilt angles of radiation required for irradiation of given zones, and the approximate intensity of the field at reception points. By this data he can judge the degree of reliability of radio reception in specific zones.

The need for such information became clear in the first years of using long-distance short-wave transmitters, when it was established that shortwave radio communication was insufficiently stable, owing to the constantly changing heterogeneity of the ionosphere on horizontal and vertical surfaces.

Partial satisfaction of this requirement, as is well known, occurred through an estimation of reception by ear, then by a measurement of voltage at the input of the receiver, later by means of a measurement of the intensity of the field near the chief radio receiving centers, and, since the second half of the 1930s, by utilizing ionospheric data and radio forecasts.

All these means and methods were of very great benefit in the development and increase in the stability of radio communication and the realiability of radio broadcasting. This made for a more effective and economic utilization of radio frequencies, and consequently an expansion of the number of radio communications and the allocation of a greater number of radio broadcasting transmitters.

However, the band of short-wave frequencies is comparatively narrow and is always overloaded; therefore it must be planned more efficiently, i.e., a still more economical utilization of it is necessary. Required at the same time is a further increase in the reliability of radio communication and radio broadcasting, which are often disturbed owing to sporadic changes in the ionosphere.

In just such a state of the ionosphere a still stronger need emerges to characterize quite correctly the conditions of radio wave propagation, especially during long-distance transmissions. For this purpose, as well as for general studies in the field of radio wave propagation, back-scatter observations have been in use in recent years. BSO allows very rapid reception, under operating conditions, of all the data enumerated above; this is extremely necessary to the engineer conducting radio communication and radio broadcasting.

BSO is based on the phenomenon of the dispersion of radio waves through the earth when waves which have been reflected from the ionosphere fall onto the earth. As far back as 20 years ago T. Eckersley [1] detected dispersed wave hops in the zone of silence and related this to dispersions from the ionosphere. These dispersions were studied by him in detail in a later work [2], in which the correctness of his original hypothesis was corroborated. In 1941, however, Edwards and Yanskiy stated the hypothesis that some back-scatter reflections can occur from irregularities of the earth's surface.

In January 1947 N. I. Kabanov showed experimentally for the first time that back-scatter reflections from distances of 1,000-3,000 km, i.e., within the limits of one wave hop, are obtained principally from the earth. In the period from August 1947 to March 1948 Hartsfield, Ostrow, and Silberstein [3], who sometimes received long-distance reflections, showed this very thing.

Later similar studies were carried out abroad by Kono [4], Dieminger [5], Peterson [6], Abel and Edwards [7], Benner [8], Sherman [9], and others. All this work, however, was done within the limits of one hop, i.e., over distances up to 3,000-3,500 km.

In 1954 we set ourselves the task of expanding the radius of BSO activity; in connection with this our work was carried out with the use of great impulse power and with high directional antennas. Moreover, we set ourselves the task of performing these experiments on operational lines and on existing technical equipment, using frequencies adopted for given transmitters, which shut out the creation of interference with other stations. This experimental work showed that there is the possibility of receiving information regularly on the state of wave propagation conditions on routes with a length up to 9,000-12,000 km, and often over the whole earth.

A pecularity of the experiments was the fact that with BSO on one frequency almost all the necessary data were received both on the state of wave propagation conditions and on the reliability of radio communication and radio broadcasting on a given radio route.

General Appraisal of the State of Wave Propagation Conditions Using Scatter Observations on One Frequency

Daily at definite times, or as needed, the transmission of impulses is done for 3 to 5 minutes during a transmission period. The duration of these impulses is of the order of the shortest signals of radio communication, and during the subsequent reception of impulses at the point of transmission onto an oscilloscope, it is possible to estimate rather well the state of wave propagation conditions, as mentioned above, for distances up to 9,000-12,000 km in a given direction. When sounding in four to five directions, evidently, one may estimate the state of wave propagation conditions over one half of the earth. The distance of the reflections of back-scatter impulse signals, their intensity, the structure and degree of variability, characterize quite fully the state of propagation conditions on a given route. Comparison of these characteristics obtained for a given moment with characteristics for a calm or a disturbed day of a given hour on the same frequency makes it possible to judge the general state of propagation conditions and the degree of reliability of reception of these transmission at various points of a given direction.

It has long been known that at definite hours in a 24-hour period on definite frequencies round-the-world echo signals are received which usually cause interference in reception and the attempt is always made to get rid of them by means of frequency change and a reduction in radiation output.

With BSO, according to the number and intensity of round-the-world echo impulses it is possible to judge radio-wave propagation conditions around the whole world in a given direction and during transmissions of impulses in several directions over the whole earth.

In Fig. 1 to 3 back-scatter reflections and round-the-world echo signals may be seen. Here in the middle is seen a signal (low rectangular) which came through the earth or troposphere; to the right are back-scatter reflections of the same impulse, obtained from various distances; to the left are round-the-world echo signals of these impulses. The whole frame equals 48,000 km; the frequency of the impulses is 6.25 per second.

In Fig. 1 and 2 a good state of propagation conditions has been established, characterized by back reflections of a high level from distances of up to 8,000-10,000 km (right half of the frames), as well as quadruple round-the-world echoes (left half).

In Fig. 3 a disturbed state of the ionosphere has been established. Here, with great amplification of a direct signal (rectangular high in the middle, the reflected back (on the right) and round-the-world (on the left) signals are weaker than the direct one, while in a normal state the back reflections and round-the-world signals are considerably stronger than the direct (Fig. 1 and 2).

Determination of Optimum Working Frequency with Oblique Sounding on One Frequency

It is known that the optimum working frequency for distance d_1 is determined from the expression [10]

$$f_1 = \frac{f^{cr}}{\cos \psi_1 \, q} \qquad (1)$$

here f^{cr} is the critical frequency during the direct fall of the wave on the layer; ψ_1 is the angle of fall of the wave on the layer, which is determined by altitude H and the distance of the hop d; q is the coefficient which allows for the thickness of the layer and the difference between the true and apparent altitude of the layer.

Evidently, for another distance d_2 and another angle ψ_2 the optimum frequency f_2 will equal

$$f_2 = \frac{f^{cr}}{\cos \psi_2 \, q} \qquad (2)$$

Taking f^{cr} and H as one and the same in (1) and (2), we have f_2 for d_2, i.e., for ψ_2,

$$f_2 = f_1 \frac{\cos \psi_1}{\cos \psi_2} = f_1 m. \qquad (3)$$

The largest wave hop is taken as equal to 3,000 km and in long-distance transmissions it is necessary to determine the optimum frequencies for a hop equal to 3,000 km. Consequently, ψ_2 corresponds to d_2 = 3,000 km. The ratio of variable $\cos \psi_1$ to $\cos \psi_2$ for d_2 = 3,000 km is given in the graph of Fig. 4.

Frequently f_1, on which we feed impulses, is known to us. We see distance d_1 on the oscilloscope (Fig. 1-3, also the idealized reflections of Fig. 5).

In Fig. 5: d_0 is the zone of silence, d_1 is the distance for which the frequency being used is optimum, d_2 is the distance for which the optimum wave must be determined. The cross-hatched rectangle designates the earth's signal; those rounded off above are the reflected-back signals. Knowing d_1 we determine m and through it f_2 for d_2 = 3,000 km.

On lines of great length this method is satisfactory when the electron density on the route is approximately identical or grows as it gets farther from the sounding point in the direction of transmission.

Such a state of the ionosphere is observed on routes for not less than half of a 24-hour period. In an easterly direction it takes place from 2100 to 0900 hours and in a westerly direction from 1800 to 0600 hours local time at the sounding point. The use of alternate sounding on both ends of the route provides a determination of optimum frequencies around the clock. However, with sufficient experience optimum frequencies can be judged around the clock and during sound from one point, since the electron density of the ionosphere changes most often by approximately the same percent in different places.

Correction of the Tilt Angle of Radiation for Irradiation of the Assigned Zone

When using high-directional antennas reflected back-scatter impulse signals are obtained as discrete signals (Fig. 1-3) and hence zones of the most intensive irradiation can be determined on the graduated scale of the oscilloscope. Obviously, by changing the angle of radiation, it is possible to direct the radiation in such a way that it will fall into the assigned zone. The discreteness of back reflections and a certain displacement of them again confirm the advisability of, and with narrow directional radiation, the necessity of, changing the tilt angle of radiation of the transmitting antennas [11].

Table 1 gives the calculated zones of irradiation.

Table 1

$H = 320$ km, $\Delta = 4^\circ$, $\beta = 4^\circ$

d_{max}	d_{min}	Irradiation Zone	Weak irradiation zone
3500 km	2750 km	750 km	
7000 km	5500 km	1500 km	2000 km
10000 km	8250 km	2250 km	1250 km
14000 km	11000 km	3000 km	500 km

Here H is the altitude of reflection, Δ is the tilt angle, β is the width of the lobe, d is the distance of the wave hop.

It should be kept in mind, however, that a highly uneven surface of the earth can create an impression of more intensive irradiation. Thus, for example, back reflections from ocean islands turn out to be more intensive than from the surface of the sea, especially a calm surface. The same thing is observed during a reflection from mountains in comparison with a lowland. This introduces additional difficulties but does not reduce the value of the necessary angle correction.

Approximate Determination of Field Length in Irradiation Zones from the Transmission Point

It is known that the length of field E at the place of reception is determined by the expression:

$$E = \frac{2.22 \cdot 10^5}{d} \sqrt{P_{\mathcal{E}}}\, e^{-G} \qquad (4)$$

Voltage at the input of receiver E inp at the point of transmission of the reflected back-scatter signal can be determined from the expression

$$E \text{ inp} = \frac{2.22 \cdot 10^5}{2d} \sqrt{P_{\mathcal{E}} R \ell}\, e^{-2G} \qquad (5)$$

Then, evidently, the length of the field at the reception point will equal

$$E = \frac{2E\text{inp}}{R\ell}\, e^{G} \qquad (6)$$

here G is the coefficient of absorption, R is the coefficient of backscatter reflection from the ground at the given point, ℓ is the effective length of the receiving antenna at the transmission point during the reception of back reflections (in the direction of the transmission), d is the distance from the transmitter to the point of back reflection of the waves, P is the output of the transmitter, $\mathcal{E}$ is the amplification of the transmitting antenna.

The coefficient of absorption G as is known, changes from day to day for the same hours of a 24- hour period. Therefore the ratio E/E inp for one and the same d during transmission on the same frequency also changes. After some experience has been gained in data of back reflections obtained at the transmission point, the length of the field at the reception point at distance d can be determined with sufficient accuracy for practical work.

At the same time, the coefficient G itself is determined. This is important for the study of wave absorption in the ionosphere. Finding E/E inp = n for various states of the ionosphere by means of simultaneous measurement of E and E inp, we find subsequently E as a product of nEinp.

When the ionosphere is calm for given d we find E and G in formula (4), and when measuring E inp we find Rℓ. Knowing ℓ, we find R. Knowing E inp, we find E, i.e., the field length at the irradiation and reception spot.

Using this method, it is possible to determine approximately the length of field for other distances, i.e., for other more distant and nearer zones of irradiation, as well as for zones located to the left and right of the given route.

Other Results of BSO

a) On the oscilloscope the width of the reflected back impulses during back-scatter observations slightly exceeds the width of the direct signal. This indicates that, in the first place, the back signal i[illegible]tly formed not on the whole swept area, but on a small part of[illegible]n the second place, the components of the signal, disregarding pa[illegible] equal length and falling on the earth and the ionosphere at different tilt angles, have different losses in the ionosphere during reflection from the earth, thus causing a contraction of the signal. In the third place, the focusing of the ionosphere is of some imprtance in the contraction of the back signal.

b) The intensity of the reflected-back signals at distances exceeding one wave hop is reduced little with distance. In winter, spring, and autumn, even in the daylight hours on the route, the intensity of the signals of back reflections at distances exceeding 5,000 to 6,000 km, is reduced a little more rapidly than inversely proportionally to the distance. This indicates the presence of long-distance wave propagation without multiple crossing by waves of absorbing layers, i.e., by means of a slide in layer F_2.

c) Photographs show that round-the-world echo signals are dispersed around the earth chiefly along the great circle arc.

d) Multiple round-the-world echo signals of impulses differ mostly, according to their intensity, only slightly. This distinction in the intensity of round-the-world echo signals is a little greater than the distinction in the path passed by waves of a different multiplicity factor of these signals. This indicates wave propagation around the earth and by paths with small wave absorption in the ionosphere, i.e., by means of sliding. This also indicates a somewhat smaller length of path of echo-signals being observed than the computed one for sudden propagation.

e) The difference in the length of the path of waves of round-the-world echo signals of adjacent multiplicity factor is not identical. The difference is often somewhat increased for the following echo signal. This can be explained by a certain delay in propagation in the ionosphere, i.e., the signal is delayed at points where the frequency in use is close to the cutoff frequency.

f) The comparatively great intensity of round-the-world echo signals, as well as back reflections within the limits of one hop, causes interference on the frequency in use in determined zones, which reduces the possibility of combining frequencies when using rather powerful transmitters.

Conclusion

Back-scatter radio observation, first utilized in the USSR and then developed for long distance use, is a powerful technical means for the study of radio-wave propagation in the ionosphere. This aspect of study permits us to send and get back marked" impulses, which imparts additional value to it.

The use of BSO in operating conditions of radio communication and broadcasting permit us to have almost all necessary information about the state of radio-wave propagation conditions not only for long distances but often over the whole earth and without obstructing the "ether," since the work is conducted on radio frequencies adopted for stations. In connection with this, BSO in its correct organization to a large degree contributes both to an increase in the effectiveness of long-distance radio communication and radio broadcasting and to a more systematic utilization of the spectrum of radio frequencies on the 6-to 30-megacycle band, which is heavily overloaded at the present time.

The author would like to call attention to the active participation of comrade engineer Yu A. Chernov of the Research Institute of the Ministry of Communications of the USSR, as well as that of engineers L. N. D'yachenko and I. I. Krasheninnikovaya, in carrying out experimental work on long-distance BSO. The following operational engineers rendered great help in carrying out the work: N. I. Fedotov, N. P. Arlamenkov, I. M. Vorob'yev, A. S. Repin, L. N. Khavskiy, V. Ya. Kvyatkovskiy, and shift-duty engineers of the MDRSV /Moskovskaya direktsiya radiosvyazi i radioveshchaniya--Moscow Board of Radio Communications and Radio Broadcasting/ and suburban Moscow radio centers.

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